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Integrating Composite Desiccant and Membrane Dehumidifier to Enhance Building Energy Efficiency

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Abstract

The paper describes the development of a hybrid solution that improves air dehumidification. It comprises the integration of a composite desiccant and a nano-woven membrane for air dehumidifcation. The solution compliments any building HVAC project where the removing moisture from the air via an energy-efficient means is a concern. Longer sustainable performance of the desiccant is achieved as the non-regenerative membrane assists in partial air dehumidification. Accordingly, the hybrid system requires a lower regenerating temperature while producing air of very low humidity. In sum, the proposed hybrid solution involves the composite desiccant and membrane to work hand-in-hand in order to achieve enhanced moisture removal efficiency and improved energy efficiency by up to 40% compared to the best grade commercial silica-gel desiccant.

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Keywords: Heat and mass transfer; Composite desiccant dehumidifier; Membrane dehumidifier, Performance analysis.

1. Introduction

In tropic countries, air conditioning (AC) has been widely used to control temperature and humidity to maintain human thermal comfort conditions and also a hospitable environment for equipment for instance computers and perishables. In Singapore alone, the total energy consumed by the air conditioning system comprises up to about 50% of the total energy consumption, and about 90% of the space cooling comes from vapour compressor systems. Additionally, the efficiency of air conditioning decreases significantly when it is required to remove increasing amount of moisture from the air. Therefore, there is a need to remove moisture efficiently before cooling the air in

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order to improve the energy efficiency of the entire cooling process. Conventionally, desiccant is employed in AC system. As air stream passes through the desiccant, the desiccant will absorb water vapour efficiently (Zhang et al. 2006). However, the water vapour absorption causes a side effect of increasing temperature of the air. Additionally, to maintain a sustainable working condition, the desiccant needs to be periodically regenerated. Although desiccant cooling system realizes a better efficiency than the conventional system, its overall efficiency is still low, because of its low moisture adsorption capacity and high thermal heat to regenerate (Jia et al. 2007).

The key objective of this work is to study the potential of a hybrid membrane/composite desiccant dehumidification system that markedly promotes moisture removal ability from humid air as well as to reduce energy consumption for air dehumidification.

2. Materials and methods

2.1. Composite desiccant synthesis

To synthesize the composite desiccant, a base desiccant material (silica gel) and a hygroscopic additive (lithium chloride) were employed for their dehumidification potential (Jia et al. 2007). We started with initial composites of silica gel and lithium chloride. The silica gel grain size used for the composites was tested and optimized by testing their performance with different lithium chloride content. The performance was then tested for composites with higher lithium chloride content. Binders were then included into the composite to tackle the issue of deliquescence and to facilitate handling of the composites (Oh et al. 2017a and Oh et al. 2017b). Subsequently, calcium chloride and bentonite were also added to promote the hygroscopic nature of the composite desiccant also the binding capability. The prepared desiccants were characterized using BET surface area measurements and water sorption testing results are shown in Figure 1b which indicate improved adsorption performance of the composite desiccants compared to silica gel.

(a) (b)

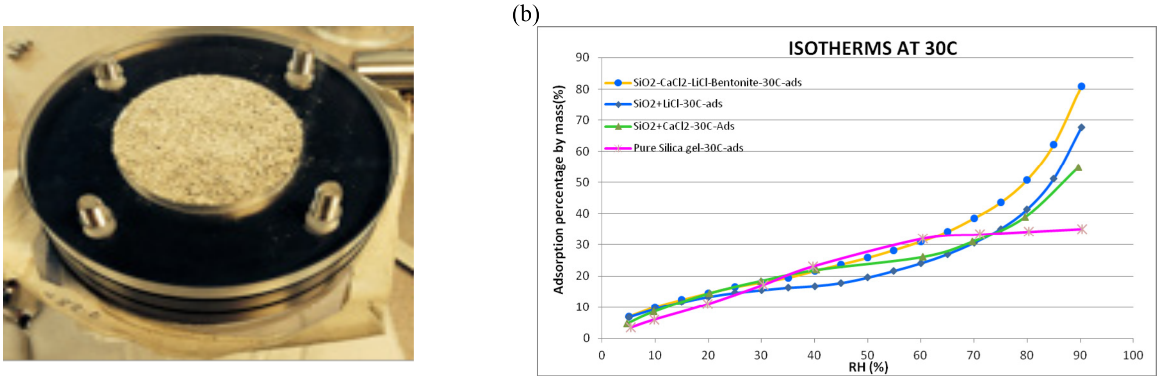

Fig. 1. (a): Photograph of composite desiccant incorporating silica gel, bentonite, lithium chloride and calcium chloride; and (b) water sorption isotherms for different composite desiccants at 30°C

2.2. *Membrane dehumidifier synthesis*

This section reports the development of a novel composite flat sheet membrane using inexpensive and commercially available materials via a green and scalable preparation method (Bui et al. 2016). The composite membrane consists of three layers, namely stainless steel scaffold, titania nanofiber layer, and hydrophilic polymer layer of polyvinyl alcohol (PVA) with lithium chloride (LiCl) with certain ratio. A titania nanofiber solution is prepared by dispersing TiO_2 nanofibers in a TiO_2 precursor sol-gel solution made from the controlled hydrolysis of titanium ethoxide in mixture of water and ethanol. A polymer solution is prepared by dissolving polyvinyl alcohol and lithium chloride in water. The titania nanofiber solution is coated onto a stainless steel scaffold by a soak coat process. The obtained titania-fibre-coated scaffold is then calcinated at 450°C for 1 min with the optimal temperature ramping up and ramping down rates. The excess titania fibre is removed. After that, the membrane is coated with the polymer solution by using a dip coater. The final composite membrane is obtained after drying it at 80°C in 1 hour.

The surface microstructure of fabricated membrane is observed using scanning electron microscope (SEM). Membrane fabrication steps and the SEM images of the membrane in each stage are summarized in Fig. 3. A thin,